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Cadence impact on cardiopulmonary, metabolic and biomechanical loading during downhill running

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ABSTRACT

Background: Distance runners can approach long descents with slow cadence and long steps, or a fast cadence with shorter steps. These approaches differentially affect mechanical loading and energy demand.

Research question: This study determined the cadence range in which biomechanical loads, caloric unit cost and energy cost were simultaneously minimized during downhill running (DR).

Methods: Trained runners (N = 40; 25.6 ± 7.2 yr; 42.5% female) participated in this experimental study. Participants ran on an instrumented treadmill while wearing a portable gas analyzer during six conditions: control normal level running (LR) at 0 deg inclination (CON-0); control DR -6 deg inclinaton (CON-6); DR at cadences +/-5% and +/-10% different from CON-6. A motion analysis system was used to capture running motion, and an instrumented treadmill captured force data. Cardiopulmonary measures, rating of perceived exertion (RPE), and biomechanical measures (temporal spatial parameters, peak ground reaction forces [GRF], vertical average loading rate [VALR], impulses) were calculated. Caloric unit cost and energy costs were standardized per unit distance.

Results: Running at -10% cadence increased HR by 10 bpm compared to CON-6 ($p < 0.0001$). Vertical excursion of the center of mass and step length were greatest in the cadence -10% and least in the cadence +10% conditions (both $p < 0.0001$). RPEs were higher among all cadence conditions compared to CON-0 ($p < 0.0001$). Caloric unit costs were lowest in CON-6, and +/5% cadence conditions compared to the CON-0 and +/-10% conditions (-2.1% to -12.3%, respectively; $p < 0.05$). Peak GRF and VALR were not different among conditions; vertical impulses were greatest in the -10% condition compared to CON-0, CON-6 and +5% and +10% by 11.3–14.5% ($p < .001$).

Significance: Changing cadence across level and downhill stretches is likely not necessary and may actually increase perceived effort of running. Running downhill at cadences that range +/-5% of preferred simultaneously minimize caloric unit cost and impulse loading.

1. Introduction

Ultra-endurance running events involve running distances longer than a traditional marathon, with a minimal distance of 50 km. Courses often feature long stretches of positive and negative elevation, and energy expenditure rate estimates have shown that runners may expend 704 kcal/h. [1] Running downhill is mechanically taxing on the musculoskeletal system [2], particularly on the knee [3]. Braking with downhill running (DR) [4] involves relatively high eccentric loading on the knee extensor mechanism compared to level or uphill running (UR) [5]. DR is related to relatively high ground reaction forces (GRF) and impact loading rates [6] but lower energy expenditure and rate of oxygen use than level or UR [7]. While UR is a common in endurance training, downhill training is not [8]. DR energy cost increases throughout ultramarathons, indicating the need to determine locomotor strategies that can counter fatigue during descent [8]. Runners can approach the descent with a slow or fast cadence, but it is unclear which cadence approach may simultaneously minimize energy expenditure and mechanical loading. This is a clinically-relevant and population-driven issue. In our institutional sports performance center, competitors often have asked how to strategically approach the course to achieve dual goals of conserving energy and minimizing loading

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characteristics at their own running speed.

What is known is that during level running (LR), manipulating cadence alters numerous kinetic and kinematic variables that relate to joint stress and injury risk. [9] Increasing cadence (at a constant velocity) can favorably impact numerous variables including braking impulses, foot strike location, patellofemoral pressures, center of pressure location and patellofemoral contact area [10–13]. There is also strong potential for cadence to modify caloric cost, as slower cadence increases leg muscle activation during stance [14] and swing phases of the gait cycle [15]; increasing muscle pre-activation with faster cadence may reduce the caloric cost associated with relatively larger braking impulses and greater vertical displacement of the center of mass associated with longer steps and slow cadence [11,15]. Thus, modifying cadence can potentially simultaneously improve biomechanical and energy cost responses [16,17] to long downhill runs. Finding the cadence range at which mechanical loads and energy cost are both optimized would be useful for runners who are planning approaches to the running course. While cadence effects on several energy-related variables and loading have been partially studied separately for downhill running, none have simultaneously examined these variables in runners at their own running speed.

The purpose of this study was to determine whether there was a cadence range at which mechanical loading (including ground reaction forces, loading rates and impulses), caloric unit cost and energy cost were minimized during short-term downhill running. It was hypothesized that compared to self-selected cadence, faster cadences would induce greater cardiopulmonary responses, caloric unit cost and energy cost and lower impact loading than slower cadences during downhill running.

2. Methods

2.1. Study design

This study used a controlled, crossover design to determine cadence-related effects on biomechanical, cardiopulmonary and metabolic variables. This study and its procedures followed the guidelines for the Declaration of Helsinki's protection of Human subjects. The study and its procedures were approved by The Univesity of Florida's Institutional Review Board (study number 201300696).

2.2. Participants

Participants were recruited using our IRB-approved running registry, web advertisements and study flyers. Inclusion criteria were: 18–40 years, currently running ≥32 km/week, able to run continuously for at least 40 min, free of acute musculoskeletal injury (such as ankle sprain, knee ligament injury), free of chronic atraumatic injuries within the preceding six months that decreased weekly running mileage (such as patellofemoral pain, Achilles tendonitis), free of symptomatic cardiovascular disease. Exclusion criteria included pregnancy ≥6 months and use of any medications that impacted balance or gait. All participants provided written informed consent.

A running-specific training history survey was administered that collected demographics, medical history and running experience. Average weekly runs, years of running, and current running shoes were self-reported. Body weight and height were measured using a standard medical grade scale. All runners had experience with treadmill running and competitive marathon distance running. Six had experience completing ultra-endurance events. Participants had previous experience competing in regional to national 5 km to marathon distance events and best performance times were provided. Characteristics are shown in Table 1.

Table 1
Participant characteristics. Values are means ± SD (range), or % of the group.

Variable	N = 40	
Women (#, %)	17, 42.5%	
Age (yr)	25.6 ± 7.2	(18.1 – 40)
Height (cm)	174.3 ± 11.5	(152.4 – 193.0)
Weight (kg)	66.4 ± 11.7	(40.8 – 89.8)
Body mass index (kg/m^2)	21.8 ± 2.1	(17.6 – 26.9)
Running experience (yr)	7.3 ± 4.7	(1 – 24)
Weekly runs (#)	4.5 ± 1.3	(2 – 7)
Best performance times		
5K (min)	20.9 ± 2.3	(17.0 – 26.0)
10 K (min)	44.1 ± 4.1	(38.0 – 50.0)
Half-marathon (h)	1.42 ± 0.2	(1.2 – 2.0)
Marathon (h)	3.7 ± 0.7	(3.0 – 5.6)
Preferred running speed, (km/h)	10.6 ± 0.8	(8.8 – 12.0)
0 deg inclination		
Preferred cadence (steps/min)	168 ± 9	(140 – 190)

2.3. Study procedures

Participants performed two testing sessions separated by not more than two weeks. During session one, participants performed a brief acclimation session of DR on the dual belt instrumented treadmill while wearing the metabolic gear and viewing the experimental visual-auditory metronome display. During session two, participants performed the actual treadmill testing and performed six different conditions of five minutes each. Metabolic, cardiopulmonary and biomechanical measures were captured during each condition. Participants ran continuously for a total of 40 min, including a warm-up, six experimental conditions and a cool-down. Treadmill speed was held constant at a self-selected speed across the six conditions. Participants were instructed to choose the speed that they would use for a long training run at least 24–32 km.

2.4. Experimental conditions

Participants first performed a normal control running at self-selected speed at 0-deg of inclination (CON-0) and a control DRcondition at -6-deg inclination (CON-6) similar to those previously used. [6,18] The same running speed was maintained for all conditions. The preferred cadence of the downhill run was determined in real-time. Four cadence targets were subsequently calculated from this preferred cadence in a range that was achievable and manageable over time: ± 5% and ± 10% [10,11,19]. The testing order of the four cadence conditions was randomized using a computer-generated randomization list and concealed using envelopes. A large flat television screen was positioned in front of the runner at eye level. A metronome mobile app (Tempo®, Frozen Ape Pte. Ltd.) was projected onscreen for the runner. The app provided a loud beeping auditory signal and the visual feedback consisted of bright red dots that would flash brightly at the same cadence as the beeping.

2.5. Cardiopulmonary measures, caloric unit and energy costs

Cardiopulmonary and caloric cost measures were obtained using a portable gas analyzer (COSMed, K4b^2; Rome, Italy). A telemetric heart rate (HR) monitor transmitted the signal directly into the K4b^2 device. HR values reflected relative exercise intensity as a percentage of age-predicted maximal HR (220-age). The analyzer captured a breath-by-breath measurement of gas exchange. Participants wore the K4b^2 unit continuously during a two minute pre-exercise baseline period, the warm-up and the experimental conditions. The relative rate of oxygen consumption ($\dot{V}O_2$), minute ventilation ($\dot{V}E$) and calories expended per minute were captured during the final minute of each experimental condition when a metabolic steady state had been achieved. Steady state in each condition was confirmed if the differences in absolute and normalized $\dot{V}O_2$ values did not differ by more than 100 ml or 2 ml/ $kg^{-1} min^{-1}$ from minute three to minute five. Standing resting $\dot{V}O_2$ was subtracted from the exercise values. [20] The caloric unit cost was determined and expressed in kcal/ $kg^{-1} km^{-1}$ and the energy cost was determined and expressed as Joules/ $kg^{-1} km^{-1}$. The mass of the portable unit was added to the body weight and accounted for in the calculations. The rating of perceived exertion values (RPE) were subjectively reported by the participant using the 6–20 point Borg scale during the final minute of each condition.

2.6. Biomechanical measures

A high-speed, 7-camera optical motion analysis system (Motion Analysis Corp, Santa Rosa, CA, USA) captured running motion at 200 Hz. Data were obtained from the last minute of each five minute condition to ensure that each runner's gait had stabilized. Thirty-three reflective markers were applied to anatomical landmarks and body segments. [21] For the static trial, markers were placed bilaterally on the acromion processes, triceps, lateral elbows, forearms, wrists, posterior superior iliac spine, anterior superior iliac spine, anterior thigh, medial and lateral condyles of the femur, tibial tuberosity, medial and lateral malleoli, calcaneus, lateral to the head of the fifth metatarsal, and medial to the base of the hallux. An offset marker was placed on the right scapular inferior angle. An initial static calibration trial was performed before data collection. The medial knee and ankle markers were removed for all running conditions.

Data were averaged from 10 consecutive strides from the final minute of each condition. The gait cycle time was expressed in percent, where 0% represented the initial foot contact and 100% represented foot contact of the same foot after swing phase. The vertical displacement of the center of mass (COM) was the difference in the maximal and minimal vertical height of the COM during an average gait cycle. Cadence was determined using commercial software using the defined foot contact and toe off events that occurred during the capture period at the running speed. Contact time was the time that the foot was in contact with the treadmill belt. These variables were calculated using commercially-available software (Visual3D, C-Motion, Inc; Germantown, MD). Bone models were developed for each runner with the individual COM location. The COM was calculated using the method described by de Leva. [22] Foot strike determination was verified on every condition for every participant by two investigators who reviewed the high speed films collected at 500 frames per second (Edgertronic; San Jose CA) in the sagittal plane.

Three measures were used to represent loading: the vertical peak ground reaction force (GRF) normalized to body weight, the vertical average loading rate (VALR) and vertical impulses normalized to body weight. Force data were collected from a tandem instrumented treadmill (AMTI; Watertown MA) at a frequency of 1200 Hz. We established a threshold of 100 N in GRF to identify initial foot contact and toe-off. GRF data were filtered using a low-pass Butterworth filter with a cutoff frequency of 40 Hz and normalized by body weight. VALR was calculated from $\Delta F/\Delta t$ from the initial linear portion of the force curve using the techniques described by Samaan et al. [23] (for curves with an initial impact peak, the ΔF in vertical GRF from 20%–80% of the initial peak over the change of time). Vertical impulses were calculated as the integral of vertical GRF over the stance time duration; both absolute values and values normalized per unit body weight were calculated relative to the force plate in each condition (vertical to the force plate in CON-0 and when the plate was tilted at -6° for the downhill conditions). Vertical stiffness, a factor that is related to bony injuries such as tibial stress fractures [24], was estimated using the following calculation: $K_{vert} = F_{max}/\Delta y$, where F_{max} is the peak vertical force and Δy is the maximum displacement of the COM. [25,26] Right and left side values for each of these measures were averaged and reported in the results.

2.7. Statistical analyses

Statistical analyses were conducted using SPSS version 24.0 (Chicago, IL). Descriptive statistics were calculated on all study variables and demographics. Normality of the data was confirmed using Shapiro-Wilk tests. General linear models were used to determine whether differences existed among the dependent variables across the six conditions. The dependent variables were biomechanical parameters (temporal spatial parameters, peak GRF, VALR, impulses), metabolic and cardiopulmonary parameters (caloric unit cost, energy cost, HR, $\dot{V}E$, calories expended per minute and $\dot{V}O_2$). The cadence condition was the independent variable (0 deg inclination [CON-0], preferred cadence at -6 deg inclination [CON-6], cadence ± 5% and cadence ± 10%). Tukey HSD post-hoc tests were used to determine where differences existed among conditions. Effect sizes between the CON-0 condition and the remaining conditions were determined using Cohen's *d* tests, where values were classified as small (0.20), medium (0.50) and large (0.80). [27] Significance was established a priori at 0.05 for all statistical tests.

3. Results

3.1. Cardiopulmonary, RPE, caloric unit and energy cost

Table 2 provides the cardiopulmonary and metabolic responses with corresponding effect sizes and significance levels. Compared to CON-0, all five downhill conditions reduced $\dot{V}O_2$ values by 8.8%–12.5%. HRs were highest in the +10% condition. The calories expended per minute were 13%–14.7% lower in the ± 5% conditions compared to CON-0.

Table 2
Cardiopulmonary and metabolic responses to different cadence conditions during downhill running.

P value represents significance of the main effect of cadence condition on each variable. Values are means ± SD.

Condition	Inclination (deg)	$\dot{V}O_2$ ($ml/kg^{-1} min^{-1}$)	$\dot{V}E$ (L/min)	Heart rate (bpm)	Intensity (%Max HR)	Calories expended (kcal/min)	RPE (6-20 points)
Control-0	0	38.3 ± 5.4	68.8 ± 16.8	154 ± 23	80.7 ± 9.6	12.3 ± 3.1	8.1 ± 2.1
Control-6	−6	32.4 ± 5.2 *	61.2 ± 10.8	148 ± 13	76.4 ± 6.7	10.5 ± 1.9 *	10.5 ± 1.7 *
Cadence +10%	−6	33.6 ± 4.6 *	66.1 ± 12.2	157 ± 15	81.0 ± 6.9	11.1 ± 2.1	11.6 ± 1.7 *
Cadence +5%	−6	32.9 ± 5.2 *	63.2 ± 11.3	155 ± 14	79.6 ± 6.6	10.6 ± 2.1 *	11.9 ± 1.6 *^
Cadence -5%	−6	33.2 ± 5.1 *	64.7 ± 12.8	156 ± 14	80.2 ± 6.5	10.7 ± 2.1	11.6 ± 1.7 *
Cadence -10%	−6	34.0 ± 5.7 *	68.4 ± 13.8	158 ± 14 ^	82.0 ± 6.5^	11.1 ± 2.2	11.6 ± 1.7 *
p (sig)		0.0001	0.051	0.006	0.026	0.011	0.0001
Effect size *d* range		0.77-1.11	0.02-0.53	0.21-0.32	0.09-0.84	0.45-0.70	1.2-2.03

GRF = ground reaction force; BW = body weight; VALR = vertical average loading rate.
* Different from Control-0, Control-6, +5% and +10% conditions at $p > 0.05$.
** Different than -5% and -10% conditions at $p < 0.05$.

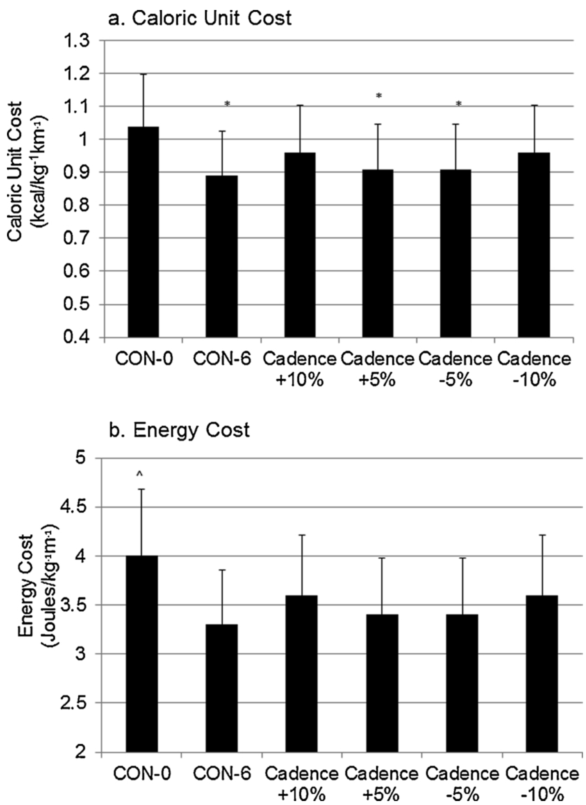

Fig. 1. a–b. Caloric unit cost of running during normal level running and downhill running (DR) different cadences. Values are means ± SD. *denotes significantly lower than CON-0 condition at $p < 0.05$.
b. Energy cost of running during normal level running (LR) and DR at different cadences. Values are means ± SD. ˆdenotes significantly greater than all other conditions at $p < 0.05$.

RPE values were 29.6%–46.9% higher in all DR conditions compared to CON-0. The $\dot{V}E$ values tended to be highest in the +10% and CON-0 conditions compared to CON-6 and -5% conditions, but this did not achieve significance.

The caloric unit costs and energy costs are shown in Fig. 1a and b. Caloric unit costs (kcal/ $kg^{-1} km^{-1}$) were highest in the CON-0 and ± 10% conditions (Fig. 1a). Energy cost values (Joules/ $kg^{-1} m^{-1}$) were highest in the CON-0 condition (Fig. 1b), with no significant differences among the DR conditions.

3.2. Biomechanical measures

Table 3 provides key temporal spatial parameters with corresponding effect sizes and significance levels. Medium-to-large effect sizes of cadence existed for cadence, COM vertical displacement, step length, stride width and contact time. Vertical excursions of the COM and step length were greatest in the cadence -10% and least in the cadence +10% conditions. Stride width and contact time were significantly greater in the cadence +10% condition.

Foot strike location, K_{vert}, average peak normalized GRF measures, VALR and vertical impulses are shown in Table 4. Fewer runners used heel striking in the +10% condition, and more used heel striking in the CON-0 and -5% condition, but these proportion differences among conditions were not significant. There was a large effect of cadence on K_{vert}. The K_{vert} in the +10% condition was significantly higher compared to -5% and -10% conditions. The differences in K_{vert} in the four cadence conditions from CON-6 were: +16.5% (+10% condition), +10.2% (+5% condition), -4.5% (-5% condition) and -11.4% (-10% condition). The effect size on the GRF and VALR variables was small. Non-normalized and normalized vertical impulses, however, were higher in the -10% condition compared to the CON-0, CON-6, -5% and +10% conditions ($p < 0.001$).

4. Discussion

The key study findings were: 1) the use of cadence values within +/-5% of the naturally-selected downhill cadence were associated with the lowest caloric unit costs, and 2) running cadence affected aspects of K_{vert} and vertical impulses but not GRF or rate of loading. Perceived effort was higher for all DR conditions compared to normal running at preferred cadence at CON-0. The collective findings suggest that staying within cadence range ±5% from the preferred downhill value does not negatively impact caloric unit cost and loading during long downhill stretches.

In the downhill conditions, a lower caloric unit may be partly attributed to less work required to raise and/or accelerate the COM with each step, and less work required by the limb segments around the body's COM. COM vertical displacement is consistently reduced and step length shortened with increased cadence. [11,19,28] Numerous studies have examined changes in energy cost and temporal spatial parameters of running on various slopes (summarized by Vernillo et al. [29]). We found the cadence range that minimizes caloric unit cost and loading during downhill running. The calories expended per minute was reduced when participants switched from level running to downhill running, and was lowest in the CON-6 and the +5% condition. This is anticipated, as preferred cadence and step length are strongly related to optimized rate of oxygen consumption compared to non-preferred

Table 3
Temporal spatial parameters and ankle angle at foot contact during running at preferred cadence.

Condition	and cadence ± 5% and ± 10% of preferred value at 6% decline.Values are means ± SD.					
	p value represents significance of the main effect of cadence condition on each variable.					
	Inclination (deg)	Cadence (step/min)	COM vertical displacement (cm)	Step length right (m)	Stride width (m)	Contact time average (s)
Control-0	0	168.3 ± 9.3	9.4 ± 1.1	1.00 ± 0.09	0.08 ± 0.02	0.259 ± 0.02
Control-6	−6	166.5 ± 9.7	9.7 ± 1.1	1.00 ± 0.09	0.09 ± 0.02	0.255 ± 0.02
Cadence +10%	−6	180.8 ± 11.3 *ˆ	8.4 ± 1.2 *ˆ	0.92 ± 0.08 *ˆ	0.12 ± 0.11 *	0.243 ± 0.02
Cadence +5%	−6	173.8 ± 9.9 ˆ	9.0 ± 1.0	0.96 ± 0.09	0.10 ± 0.03	0.248 ± 0.02
Cadence -5%	−6	160.0 ± 8.2 *	10.6 ± 1.2 *	1.03 ± 0.10	0.09 ± 0.03	0.264 ± 0.02
Cadence -10%	−6	154.2 ± 8.3 *ˆ	11.4 ± 1.5 *ˆ	1.08 ± 0.09 *ˆ	0.10 ± 0.03	0.268 ± 0.02**
p (sig)		0.0001	0.0001	0.0001	0.028	0.0001
Effect size *d* range		1.2-1.6	0.87-1.5	0.88-0.94	0.5-0.78	0.35-0.65

GC = gait cycle; COM = center of mass.
*different from Control-0; ˆdifferent from Control-6 at $p < 0.05$; ** different from +10% faster, +5% conditions at $p < 0.05$.

Table 4
Biomechanical variables during the six study conditions. Values are means ± SD or percent of the group.

Condition	Inclination (deg)	Heel striking (% of group)	K_{vert} (N/cm)	Peak GRF (BW)	VALR (BW/s)	Impulse (N·s)	Normal Impulse (BW·s)
	p value represents significance of the main effect of cadence condition on each variable.						
Control-0	0	75	17.9 ± 0.4	2.50 ± 0.36	65.4 ± 26.2	249 ± 44	0.38 ± 0.04
Control-6	−6	72.5	17.5 ± 0.4	2.54 ± 0.40	73.5 ± 29.4	250 ± 44	0.38 ± 0.04
Cadence +10%	−6	57.5	20.4 ± 0.4 *	2.54 ± 0.36	66.8 ± 27.5	235 ± 42	0.36 ± 0.05
Cadence +5%	−6	65	19.3 ± 0.4 **	2.61 ± 0.41	67.6 ± 22.3	245 ± 44	0.37 ± 0.04
Cadence -5%	−6	75	16.7 ± 0.4	2.65 ± 0.44	75.1 ± 28.8	268 ± 45	0.41 ± 0.05
Cadence -10%	−6	70	15.5 ± 0.4	2.64 ± 0.43	71.9 ± 21.9	274 ± 44 *	0.42 ± 0.03 *
p (sig)		0.499	0.0001	0.409	0.569	0.001	0.0001
Effect size *d* range		———	1.0-6.25	0.11-0.37	0.09-0.35	0.35-0.54	0.25-1.13

GRF = ground reaction force; BW = body weight; VALR = vertical average loading rate.
* Different from Control-0, Control-6, +5% and +10% conditions at p > 0.05.
** Different than -5% and -10% conditions at p < 0.05.

cadence and step lengths [30]. In ultra-endurance events of 54-km, a negative energy balance averages 4732 kcal over a 14 -h run [1]. Thus, even small improvements in energy conservation can help reduce the negative energy balance for ultradistance runners. If we use average weights of ultradistance runners aged 18+ years (54.7 kg female, 71.9 kg male) [31] we estimate that keeping cadence within ±5% the preferred downhill value would only cost 54–143 kcal more for men and women during downhill stretches of a 50 km or 100 km race. This cost would double if cadence increased or decreased by ±10%.

Runners consistently rated RPE higher in all downhill conditions compared to CON-0. Effort ratings may reflect the complexity or unaccustomed nature of the cadence tasks. Participants feedback indicated: 1) concentration was required to run downhill with a mask that restricted visibility of the belt below the feet, and 2) achieving and sustaining consistent cadences was mentally challenging. Kolkhorst et al. [32] found that DR produces higher perception of exertion than level running. Among several physiologic factors in graded running, respiratory-ventilation rate pattern changes [33] can modulate the sense of work effort. Thus, it is likely that several factors contributed to the higher RPE values, including mental concentration of the cadence conditions, relative running intensity and ventilation patterns.

Acute cadence modification affects GRF and impact loading during level running. [9,11] Among a group of runners who were asked to run at self-selected speeds at progressively greater cadence was largely maintained, but higher braking GRF occurred [6]. An inverse relationship exists between cadence and peak vertical GRF; compared to preferred cadence, 5%–10% higher cadences reduce GRF by 0.8–2.5% [11]. Others have demonstrated higher vertical GRF peaks during downhill versus level running [34,35]. Here, GRF values increased 0–4.3% from high to low cadence conditions but this was not statistically significant. Possibly, our GRF force curve patterns could suggest that either landing patterns were tentative and soft due to fear of falling, or a change in optical flow occurred as has been shown with running [35]. Runners did not consistently shift the foot strike location from heel to mid/forefoot with cadence to help soften the landing. As such, there could be non-mutually exclusive events occurring simultaneously that produced consistent GRF values across conditions. These events include different loading patterns between foot strike types ([36]) and different levels of leg muscle preactivation for each cadence. The VALR during DR was not significantly altered with variations in cadence. Loading rate reductions occur with level running using similar step manipulations as ours [37]. We also detected an effect of cadence on impulses in the -10% condition. This finding is comparable to others, where 5%–10% faster cadences reduce force impulse per step and relieve plantar impulse loads during level running [37,38]. While the cadence effects appear small, the cumulative impact of reducing impulse with each step can be large. Investigators estimated that for over every mile of running, a small reduction in impulse due to cadence change can offload 565 bodyweights/second at the heel and 140–170 bodyweights/second at the forefoot [38]. This per-mile savings is especially important during long distance and ultramarathon events as it may reduce stress on the lower extremity bones and soft tissues.

4.1. Limitations and strengths

We did not track running responses over a duration simulating a marathon event. Possibly runners may generate different mechanical, [39] cardiopulmonary and metabolic responses as fatigue develops. Moreover, the natural outdoor downhill terrain surface is typically uneven (rocky, tree roots, pocked) and can contain stretches of much steeper decline slopes tested here. We acknowledge that energy cost decreases until -20% slope, after which energy cost rises again [7].We did not test steeper slopes that ultra-distance runners may encounter. Participants also reported that adjusting to non-preferred cadences was technically challenging. Had participants adapted fully to these unnatural experimental conditions with more extensive practice, we may have detected differences in the RPE and other cardiopulmonary variables. Finally, the running intensity relative to the lactate threshold was not determined in these runners, and this may impact energy measures collected in this study. The strengths of the study include comprehensive simultaneous assessment of metabolic, cardiopulmonary and biomechanical variables (temporal spatial parameters, peak GRF, VALR, impulses) that can impact performance and injury risk.

4.2. Conclusion

Maintenance of cadence values for downhill distances that are within ± 5% of the preferred level appear to have implications for conservation of energy and protection of lower extremity joints. DR for extended periods at cadences -10% may increase relative intensity of running, loading impulses and force attenuation by the lower extremities.

Conflict of interest statement

The authors have no financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Disclosure

The authors have nothing to disclose.

Declarations of interest

None.

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